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Songs from the Milky Way: Our galaxy in low frequency gravitational waves

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Songs from the Milky Way:

Our galaxy in low frequency gravitational waves

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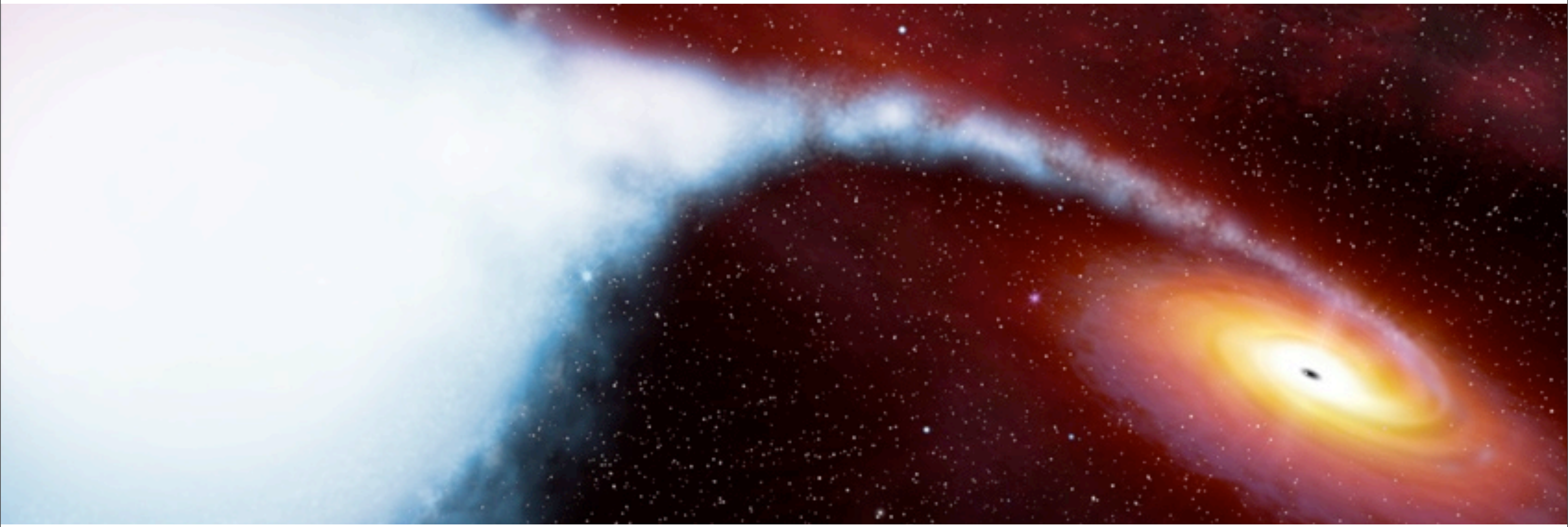
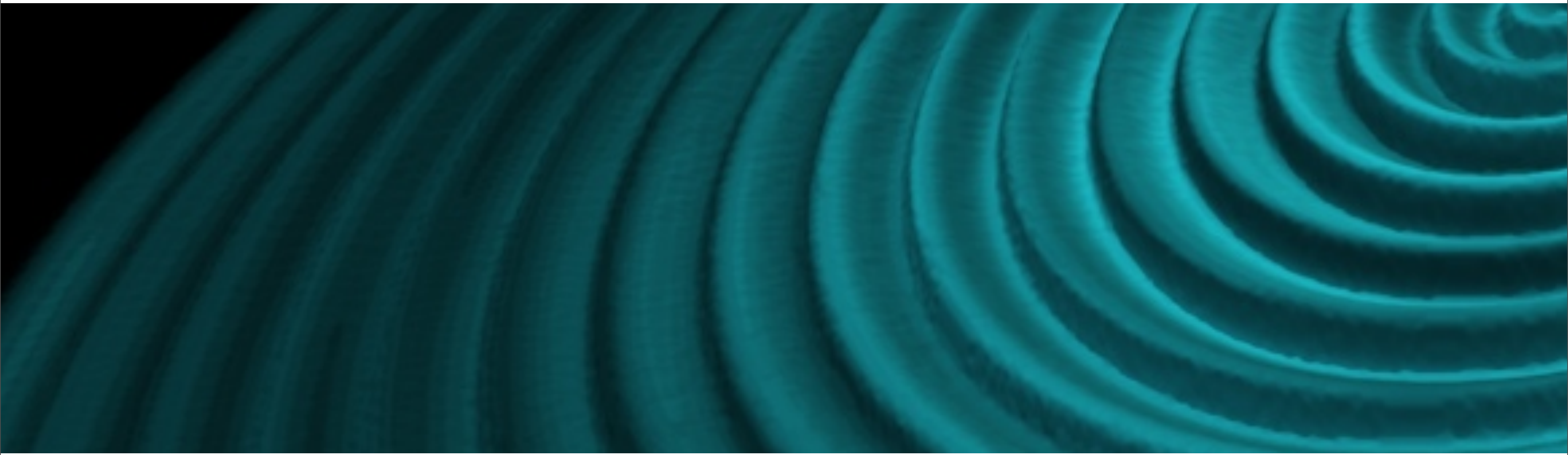
Storyline



- Gravitational waves, detection & LISA
- The sounds of the binaries
- The Galaxy in Gravitational Waves

- Binaries are **SIGNAL** not **NOISE**

Einstein in analogy to Maxwell...



- Electromagnetic waves are the *wavelike solutions* of the Maxwell Field Equations.
- Gravitational waves are the *wavelike solutions* of the Einstein Field Equations.
- Amplitudes, frequencies, and polarization states (2 for GR), and propagate at **v = c**
- Gravitational waves are **transverse**

Wave action on particles...

- A passing gravitational wave changes **proper distances** in a plane transverse to the direction of propagation
- Characterized by a **dimensionless strain h**

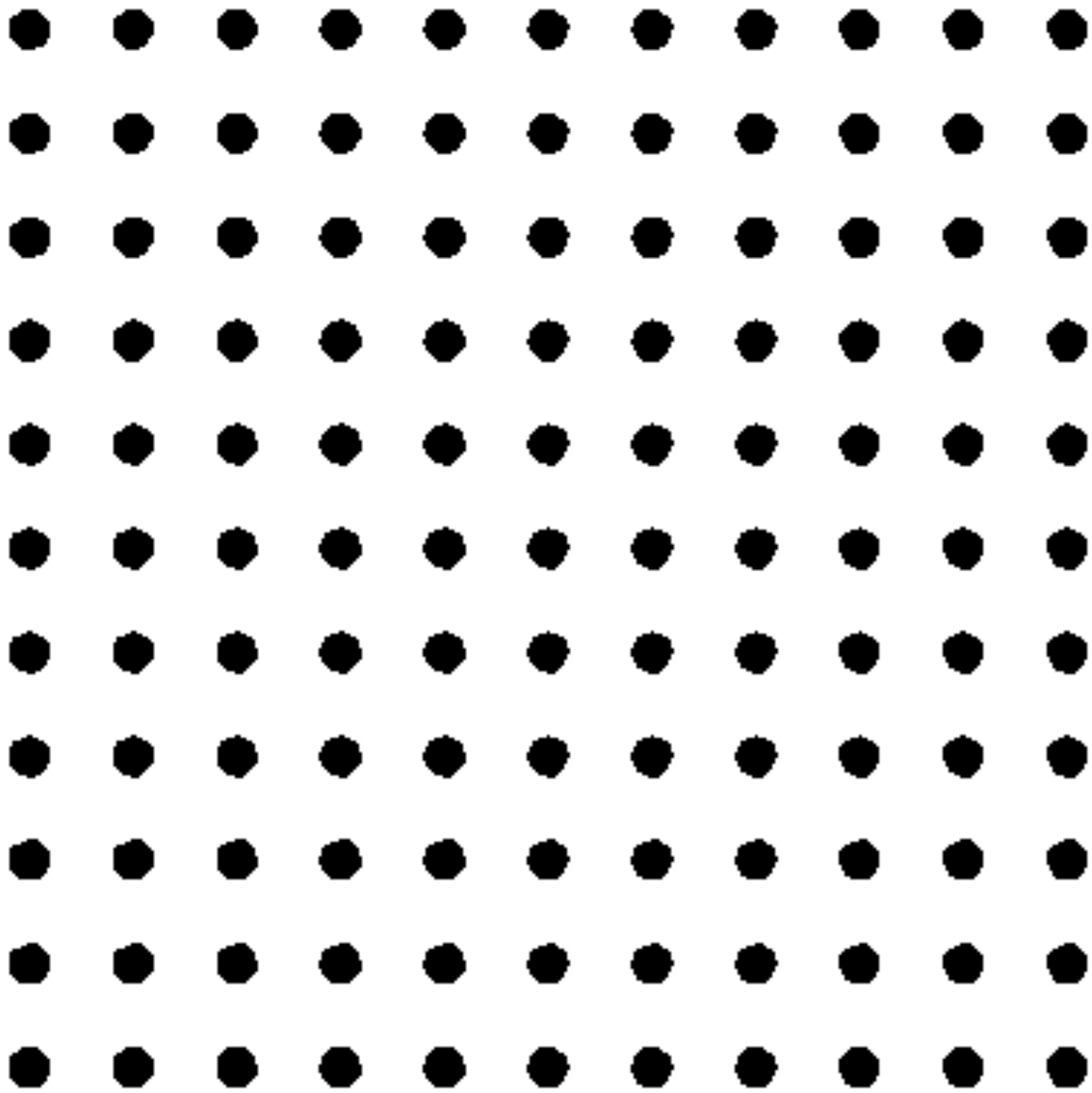
What you have to measure; fixed by your experimental capability

Real world input, fixed by astrophysics and is usually SMALL!

$$h = \frac{\Delta L}{L}$$

What you can control – the size of your experiment! Fixed by your pocketbook

Wave polarizations



Typical Wave Strengths

Angry Motorist:

$$h \sim 7 \times 10^{-52}$$

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NS Binary at Galactic Center:

$$h \sim 5 \times 10^{-23}$$

What does h ~ 10^{-23} mean?

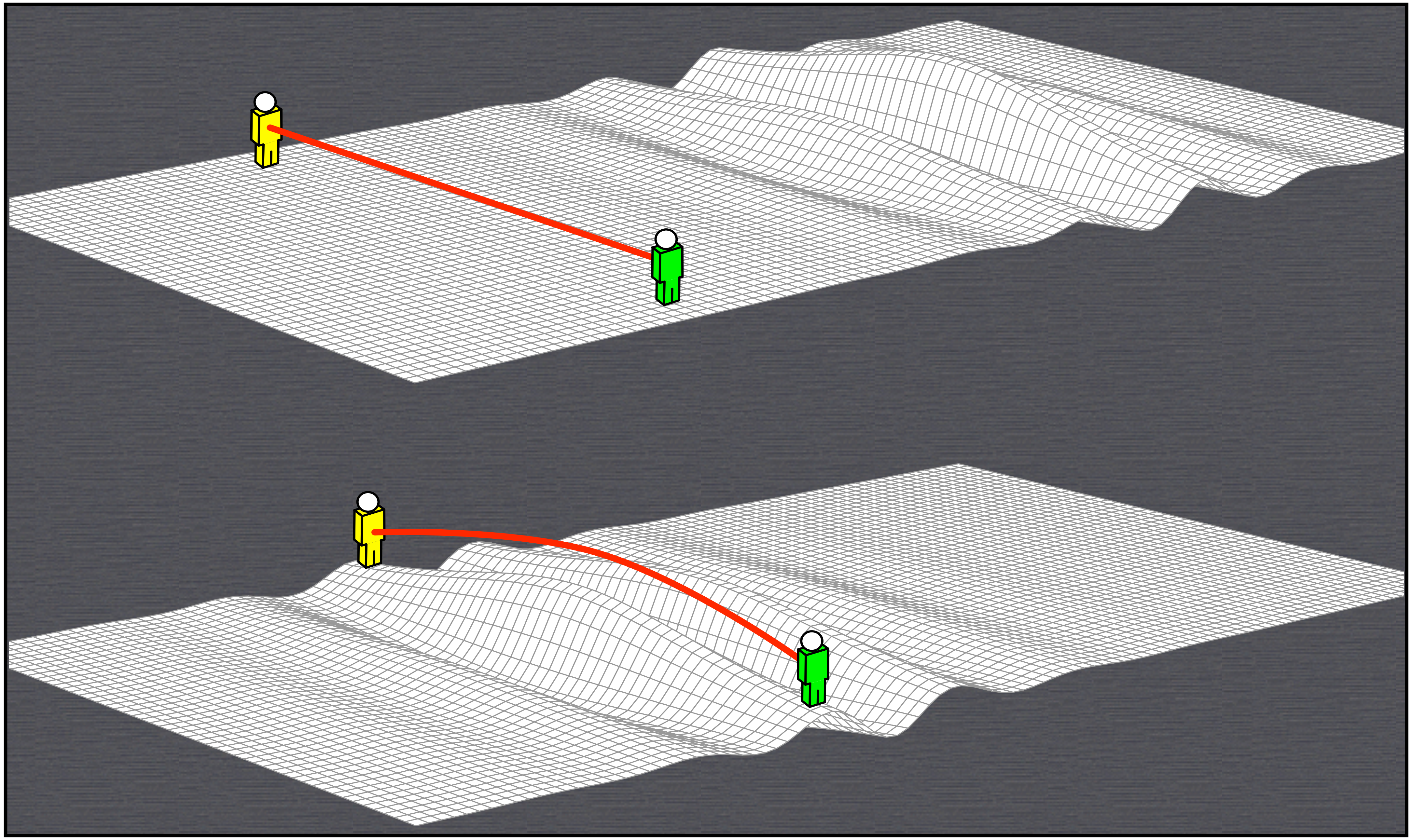
- Think in terms of an **experimental apparatus**

$$L = \frac{\Delta L}{h}$$

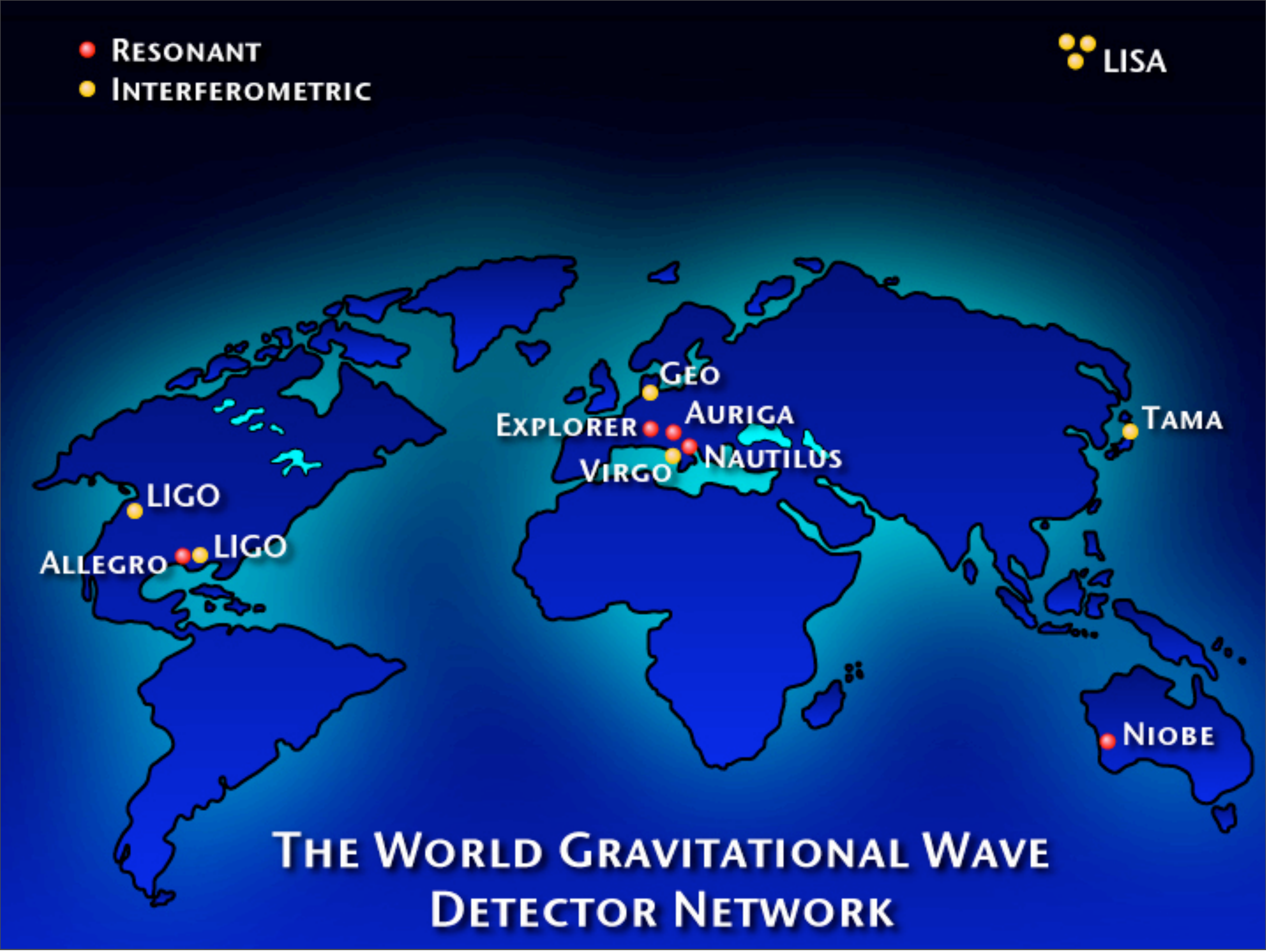
$$\Delta L = 3 \times 10^{-13}\ m$$

$$L = 5 \times 10^{9} m$$

- How do you measure this? **Use light...**
- On a scale of millions of kilometers? **Go to space...**

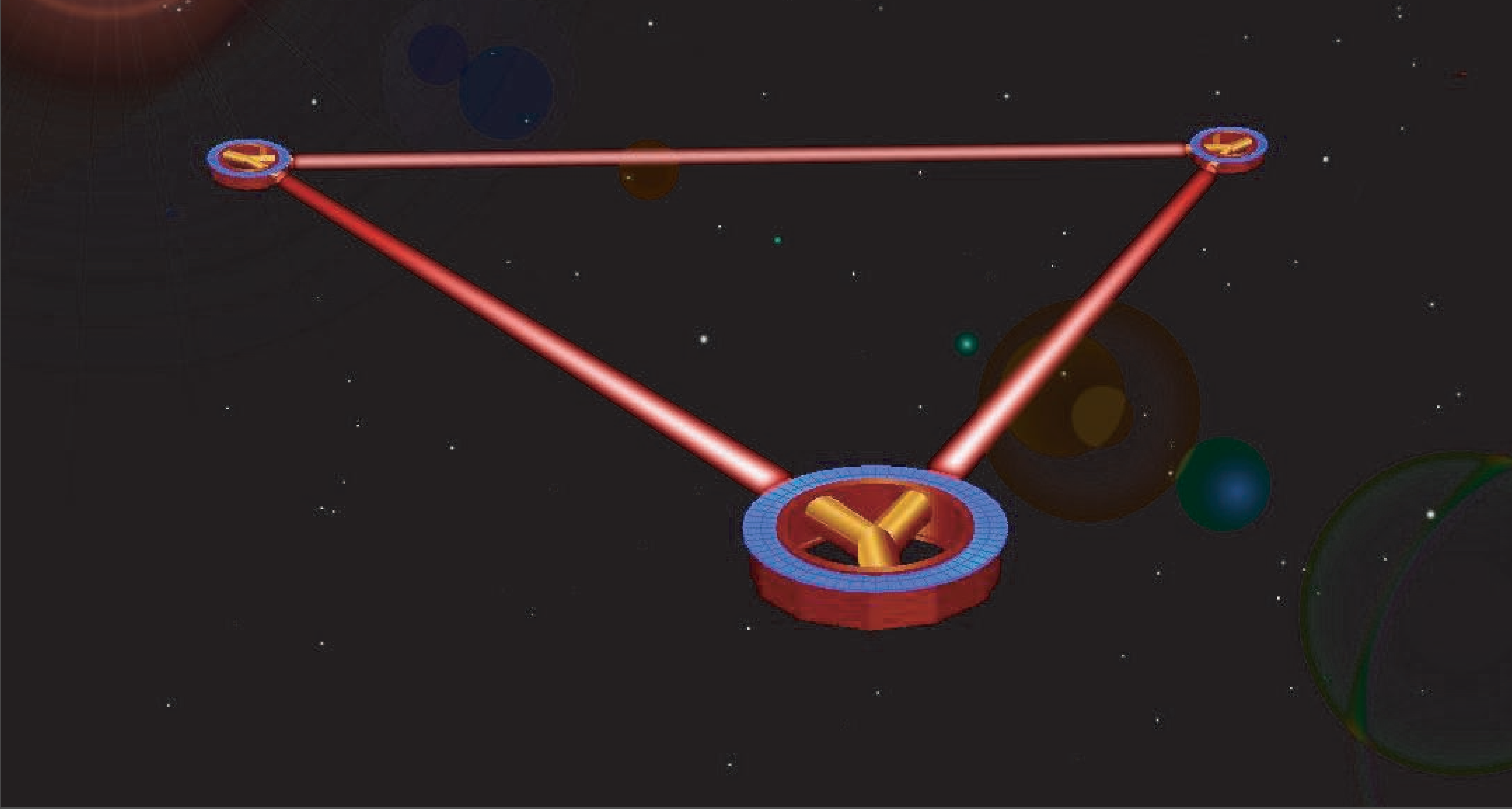


- Characterize change in distance by the strain $h = \Delta L/L$
- Typical values: $h \sim 10^{-23}$ implies $\Delta L \sim 10^{-13}$ m

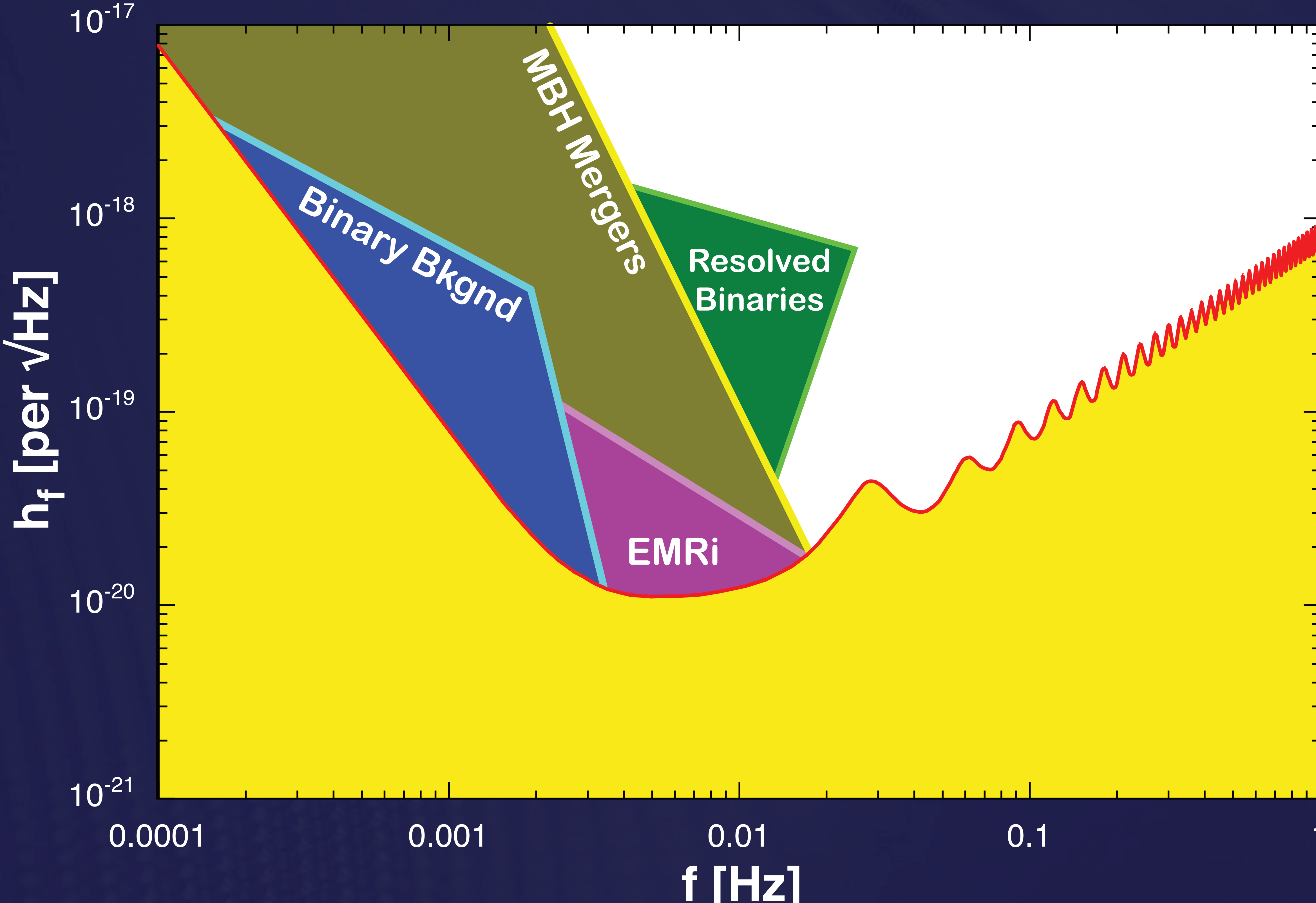


Resonant
Interferometric
LISA
Geo
Auriga
Explorer
Tama
Nautilus
Virgo
LIGO
LIGO
Allegro
Niobe
The World Gravitational Wave
Detector Network

- LISA (joint NASA/ESA mission)
- Launch ~ 2016
- Baseline: 5 million km
- Frequency: ~ 10^{-5} Hz to 1 Hz



LISA Discovery Space



http://www.srl.caltech.edu/~shane/sensitivity/

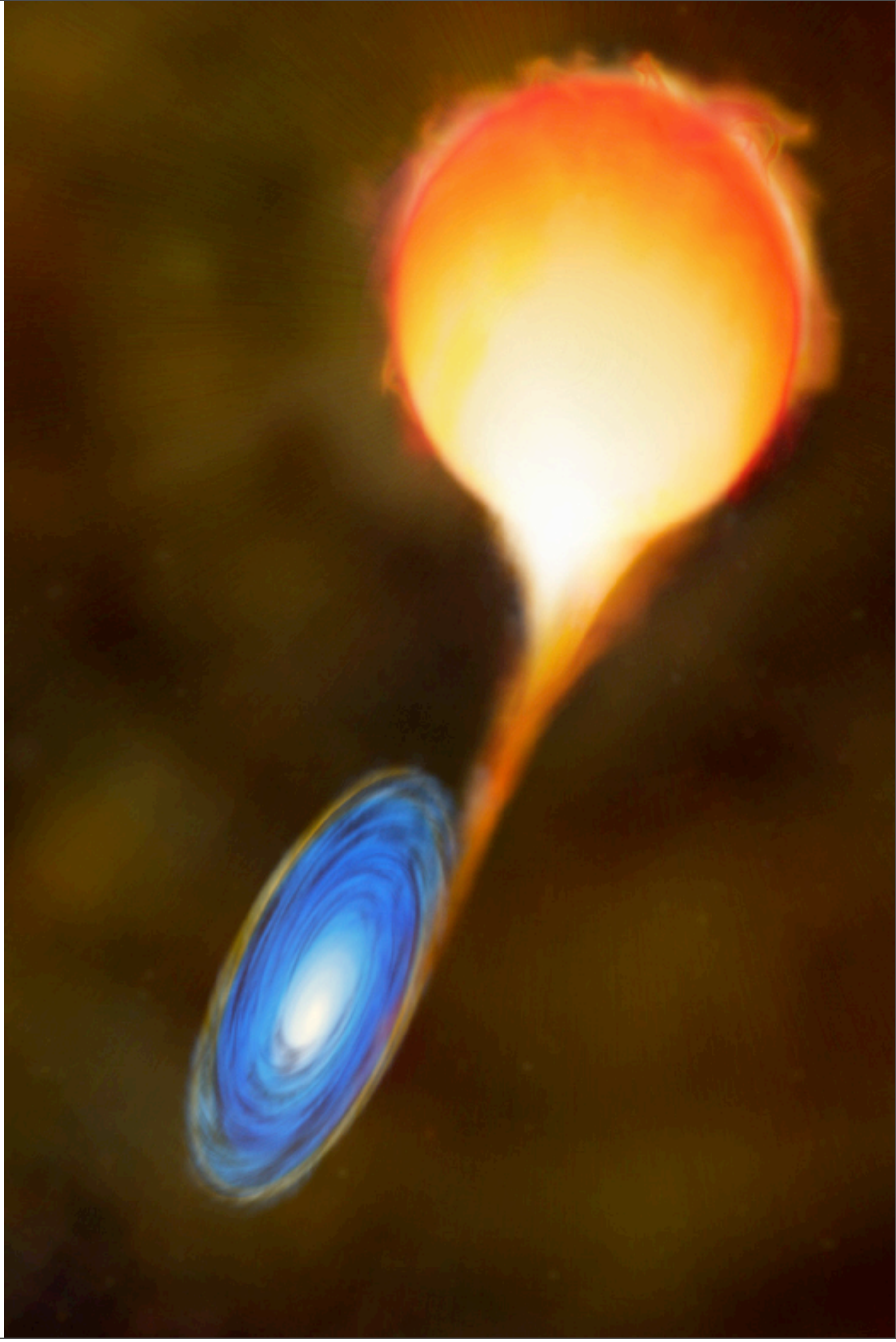
Larson, Hiscock & Hellings (2000)

The Milky Way

- Roughly 100 billion stars
- Many (most) stars are in binary systems
- For gravitational waves, we want short period binaries
- P_{orb} < few hours
- Must have compact stars (white dwarfs, neutron stars, stellar mass black holes)
- 10 million close binaries in the galaxy

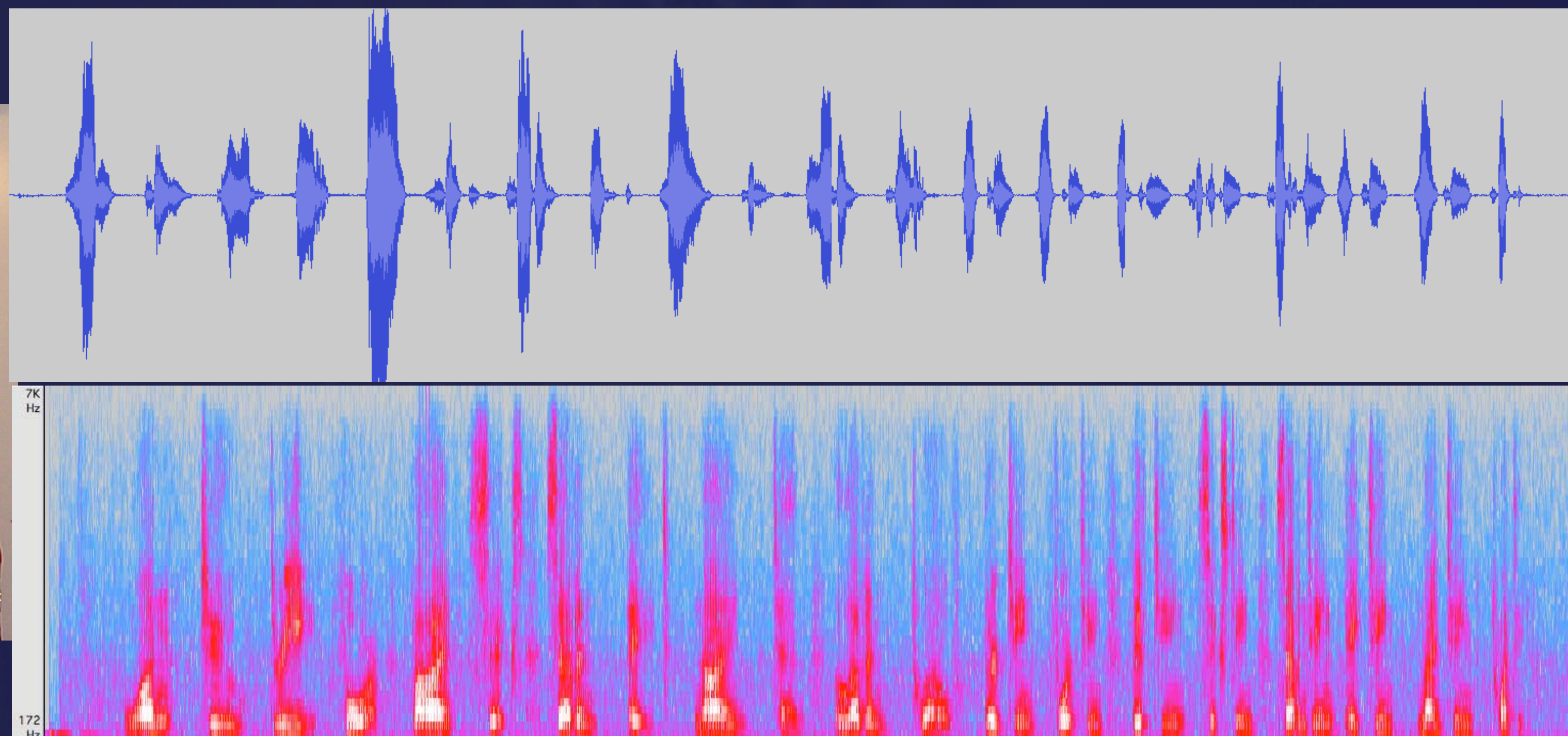
The Close Binaries

- There are so many binaries, their signals overlap, and it is difficult to tell them apart
- This is called the "**confusion limit**", and is analogous to a cocktail party
- You can hear people **nearby**
- You can hear **loud people**
- Alll else is a **dull noise**
- ~10,000 binaries will be separable from the confusion
- Teaching computers to sort this out is **hard**



Confusion Demonstration

- A simple demonstration can be shown with sound
- Consider 3 overlapping signals (first people, then stars)



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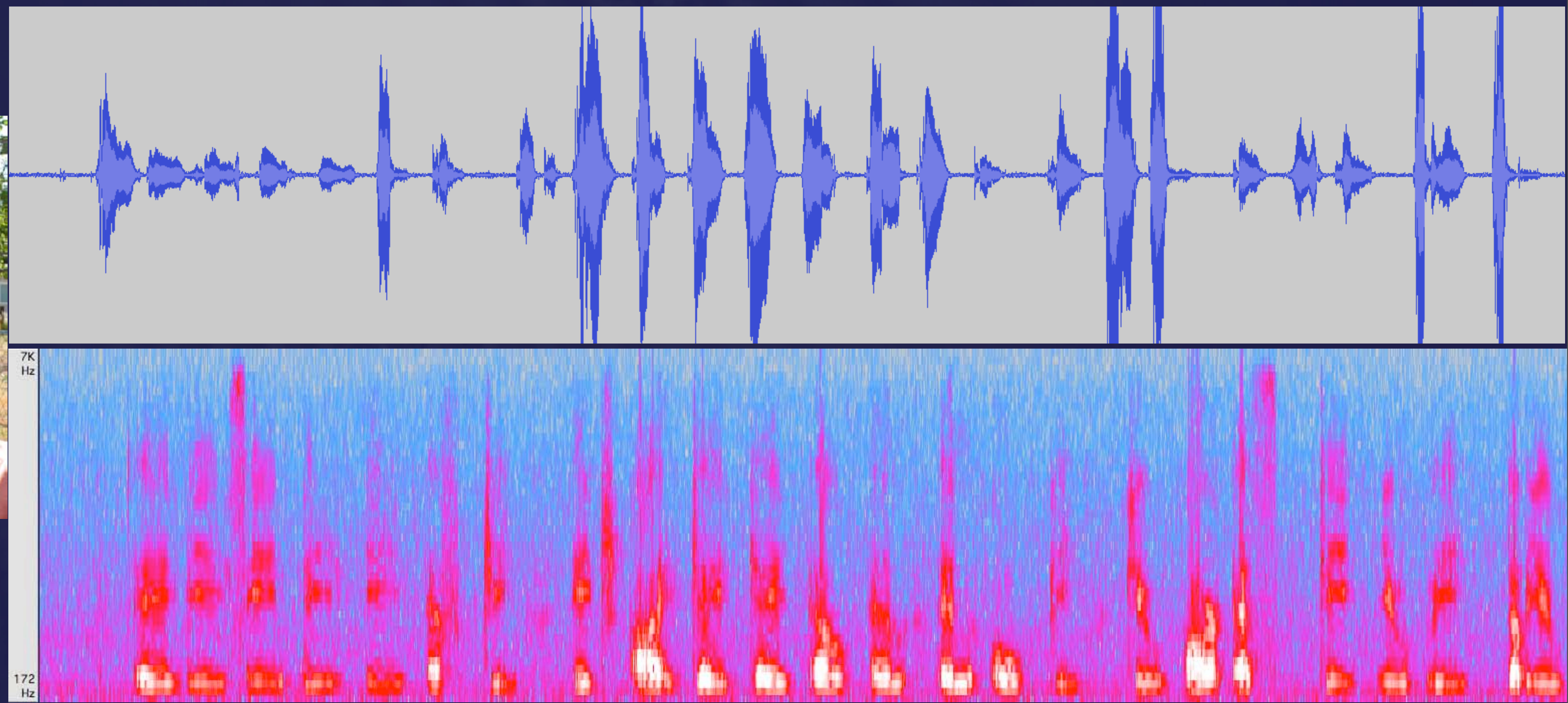

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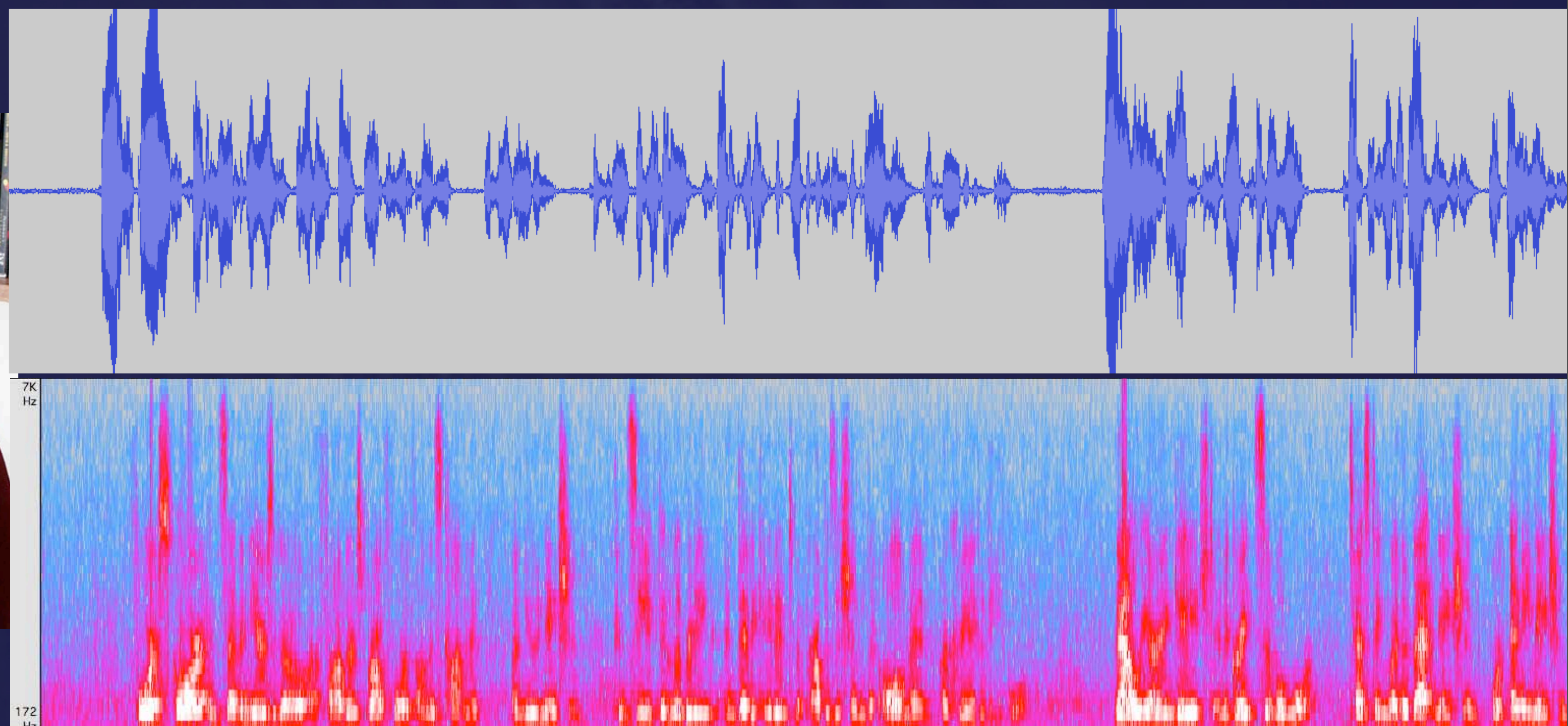
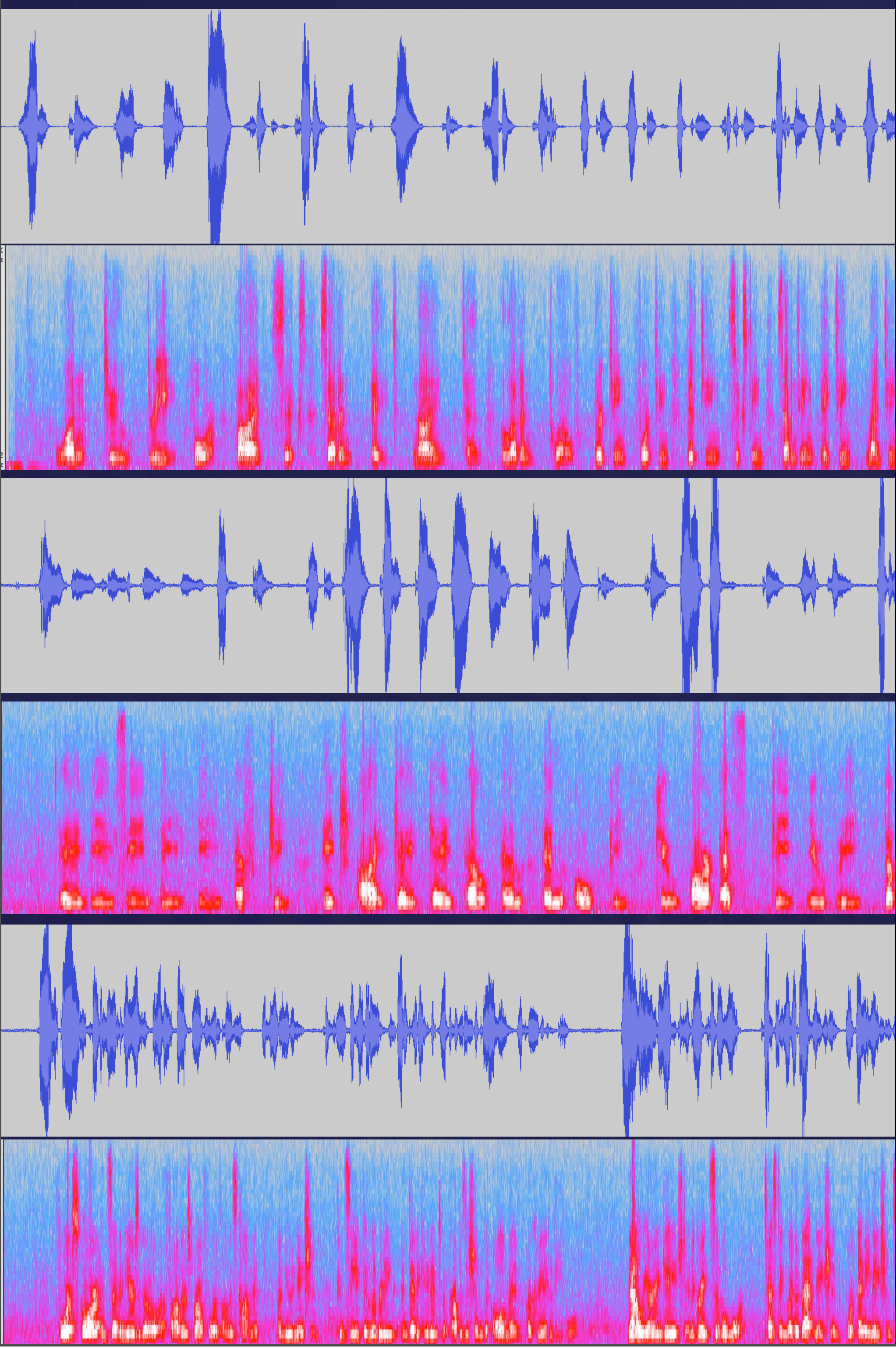
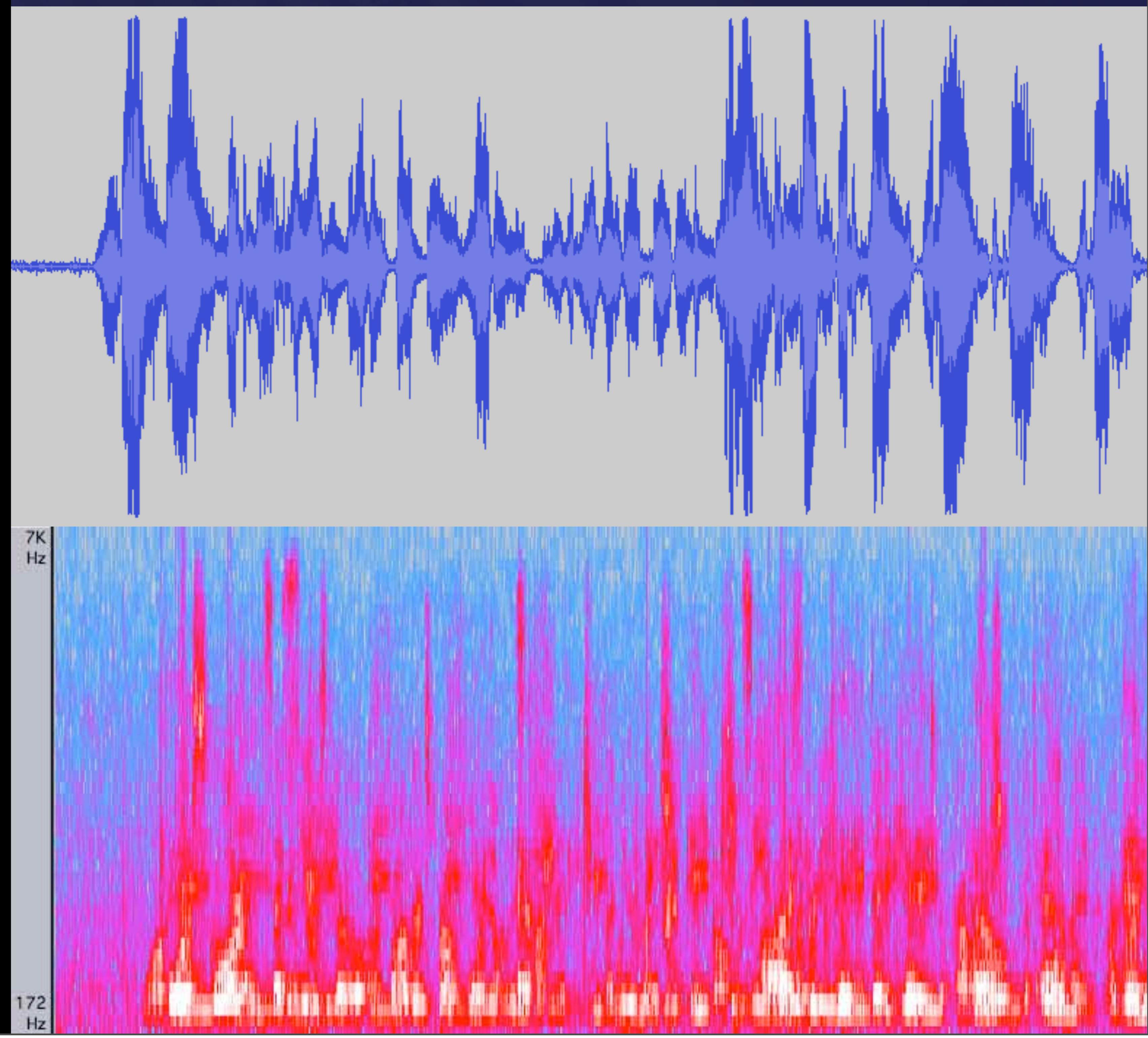


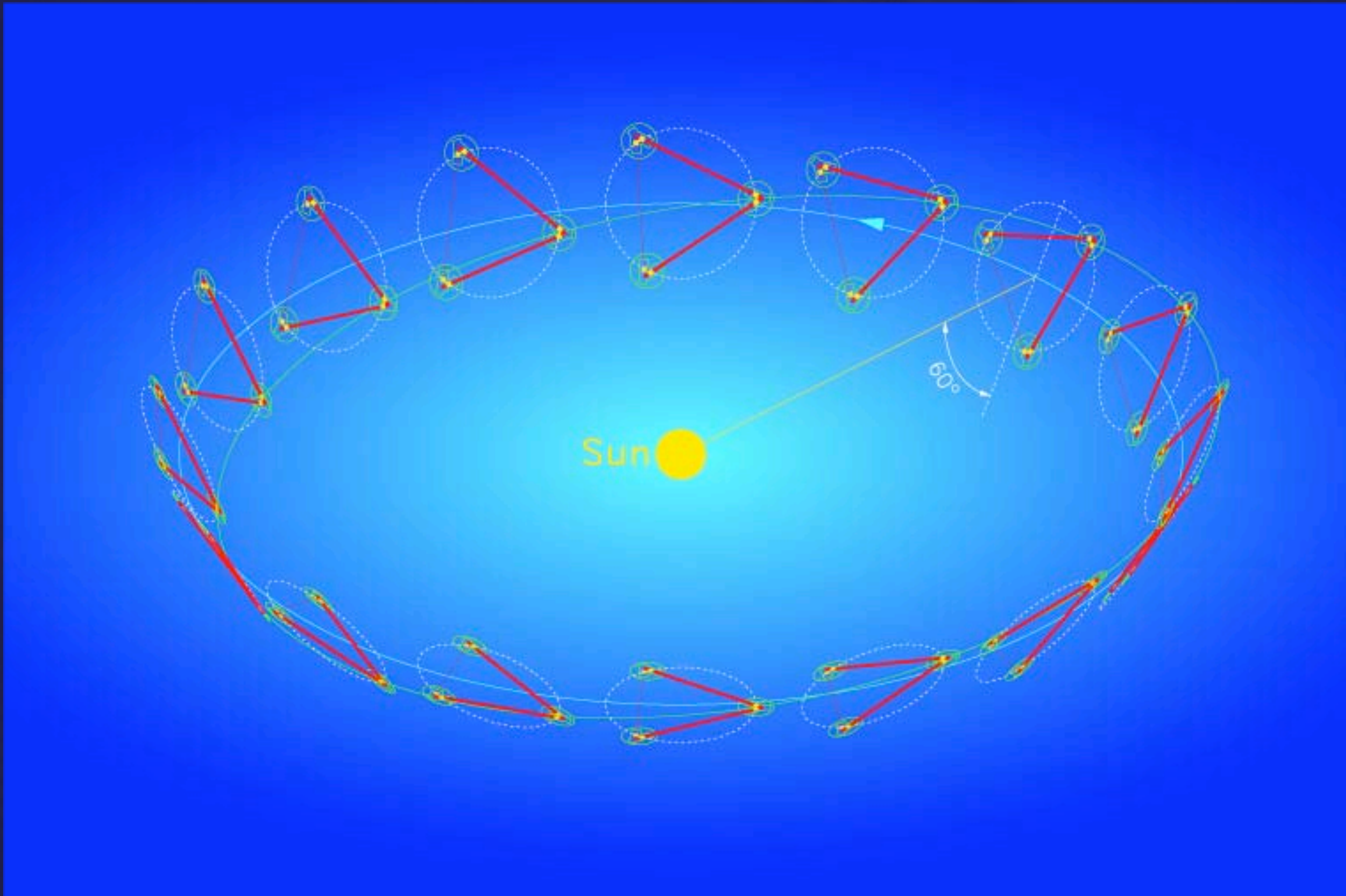
Confusion Demonstration

- When they are overlapping, it is hard to pick individual signals out — with your eyes (or computers). Your ears do just fine!





Songs of the Binaries

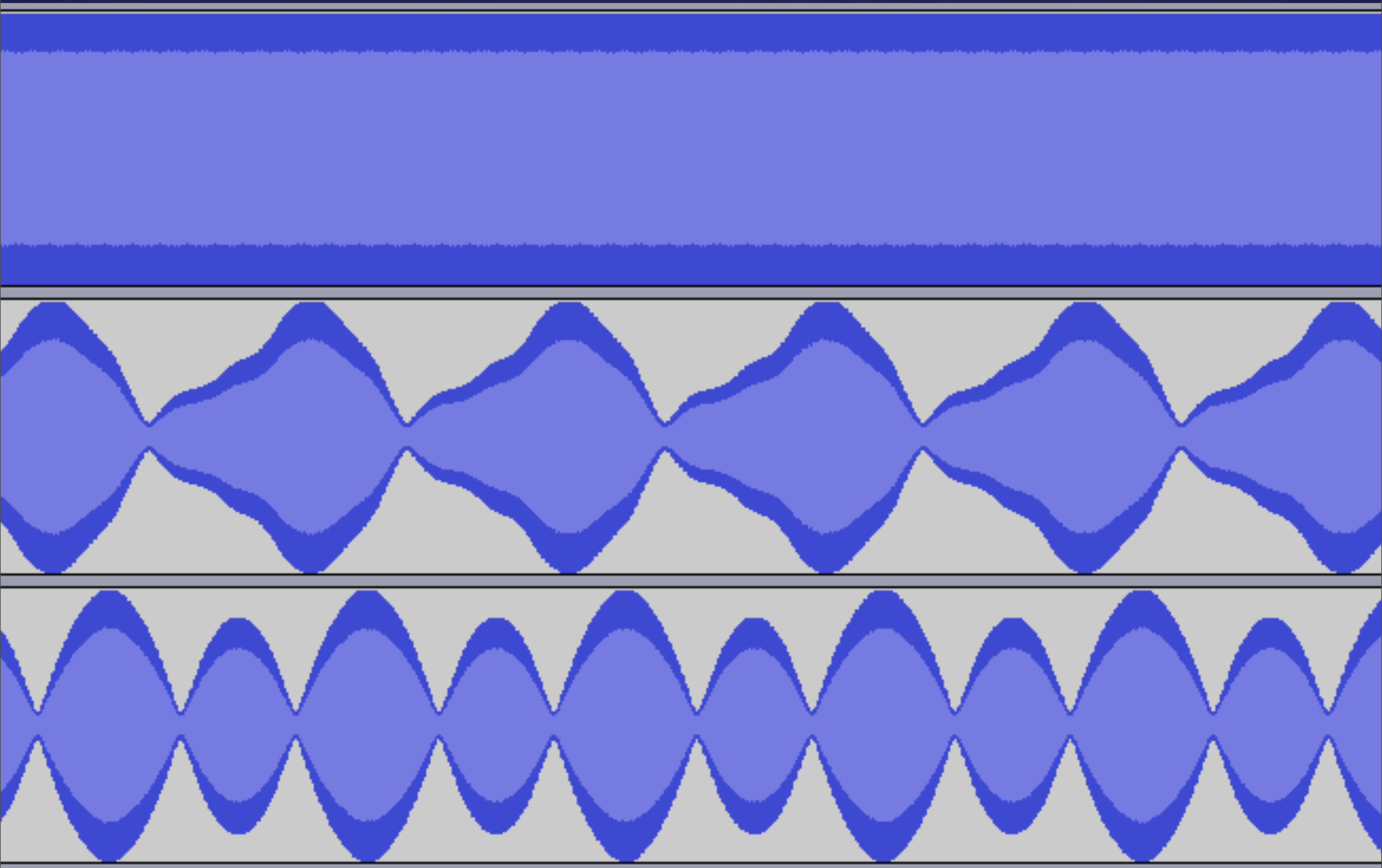


Songs of the Binaries

- LISA's motion also complicates the received signals
- LISA is omnidirectional, so it points everywhere!
- Motion of LISA modulates signals!

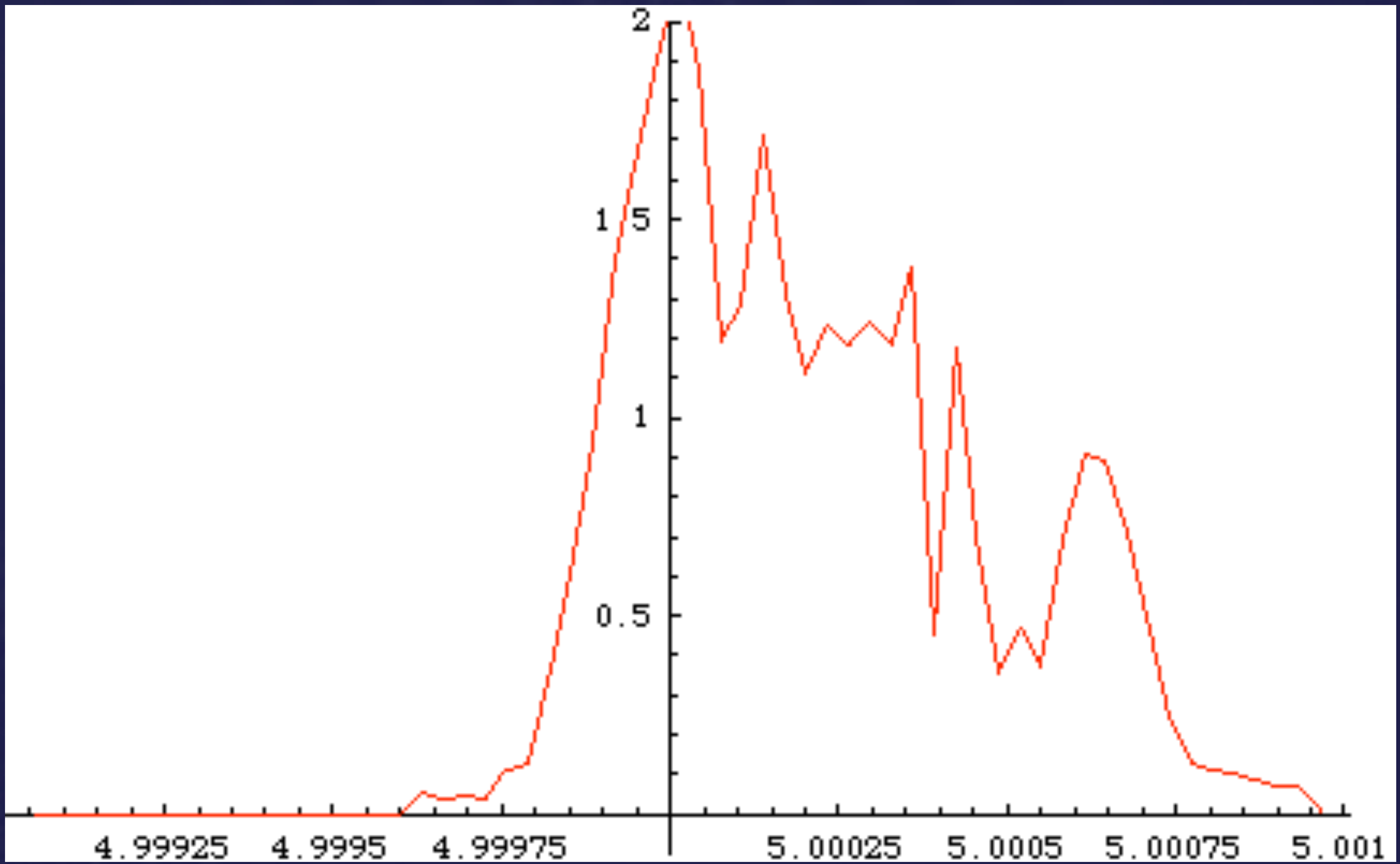
Monochromatic	lat = $\pi/4$ long = $\pi/16$	lat = $\pi/16$ long = $\pi/2$

Songs of the Binaries



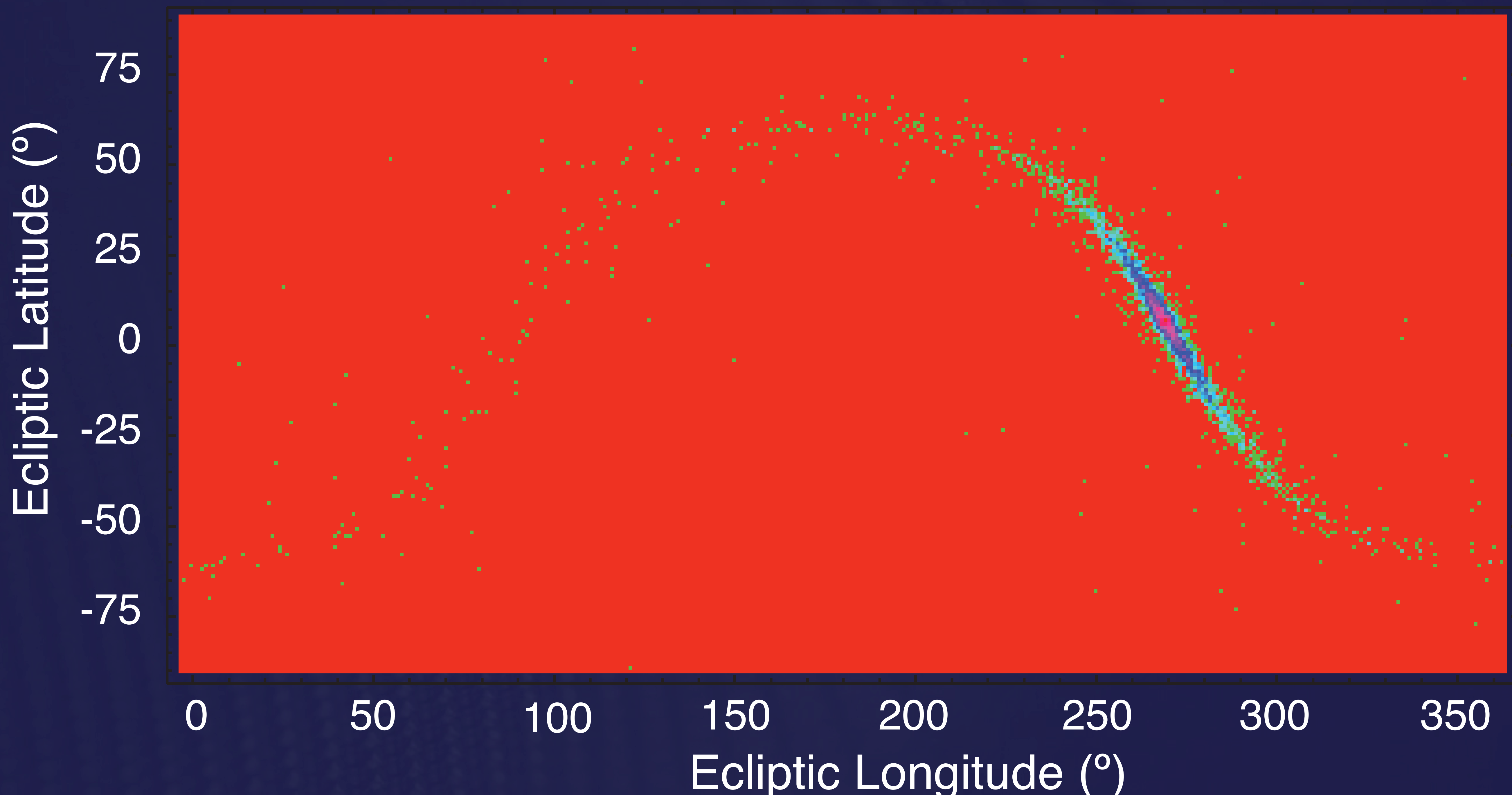
Resolving single binaries

- Slide a template over the data, and look for match
- When you find a match, subtract a tiny bit off
- Iterate! Add up all the tiny bits at the end.
- This technique is called gCLEAN.



Cornish & Larson (2003); Larson & Finn (2006)

Binaries in the galaxy



Larson, Benacquista & Taylor (in prep)

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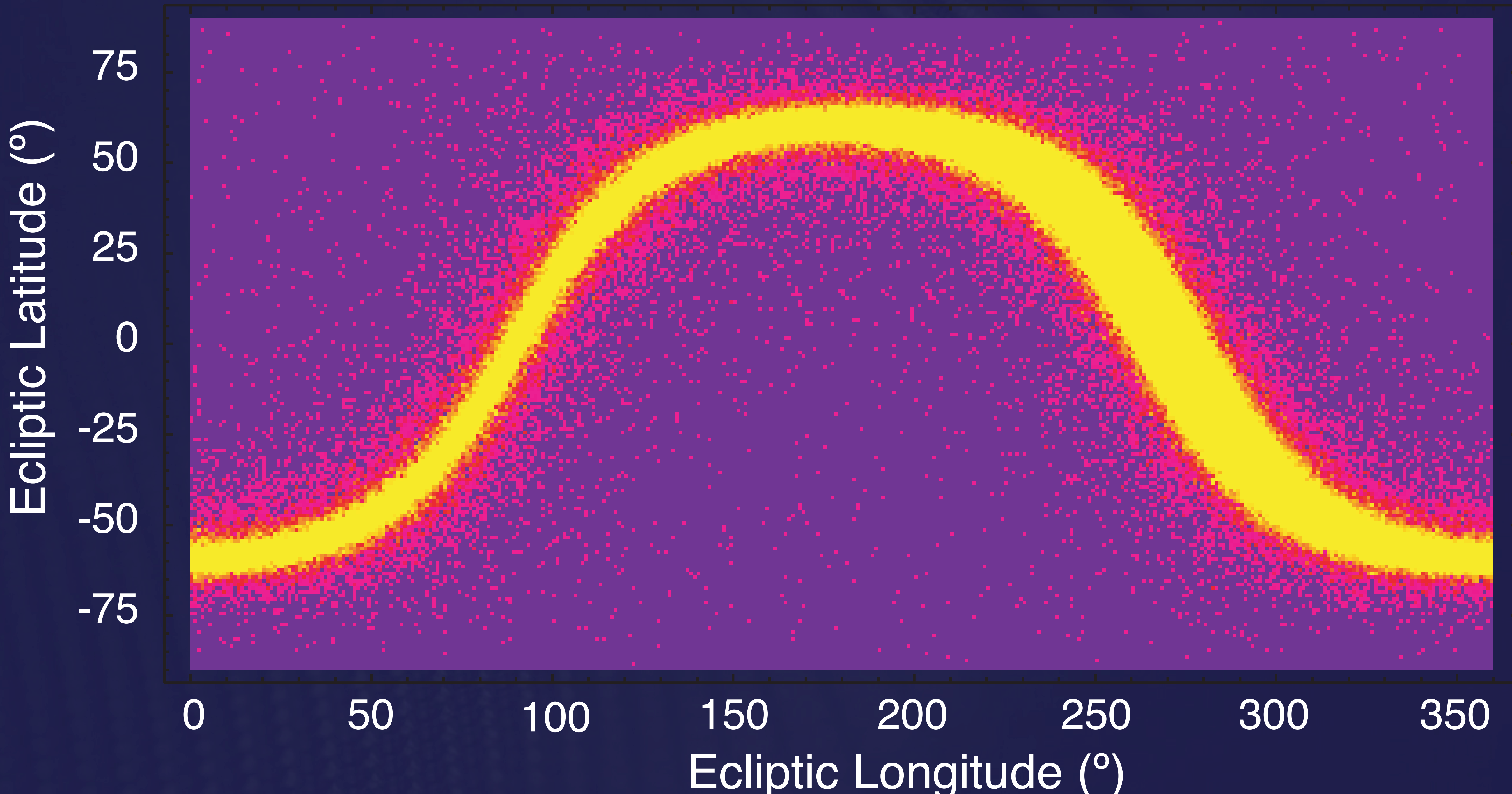


Larson, Benacquista & Taylor (in prep)

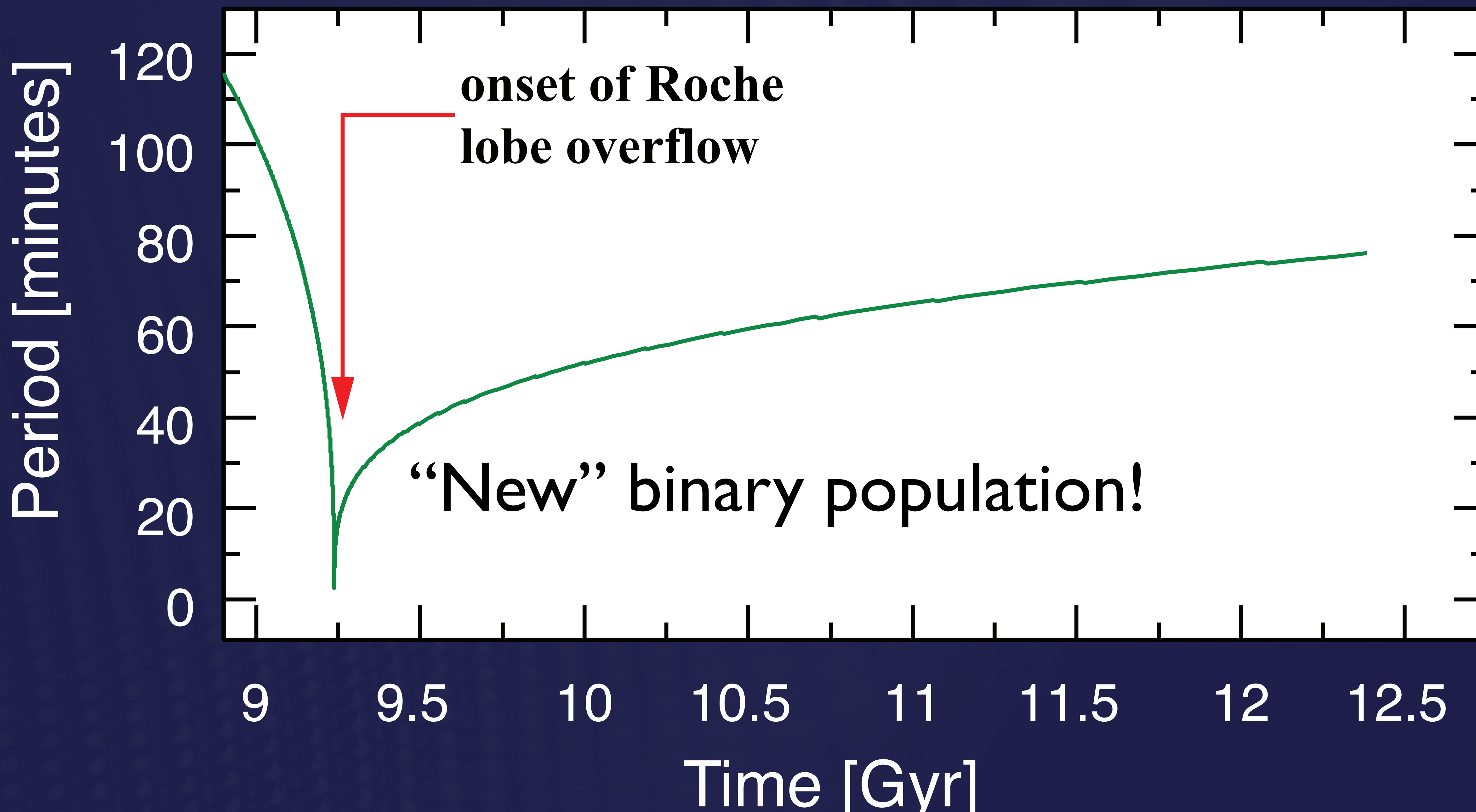
Population synthesis models

- Our knowledge of GW binaries is limited to those close by that can be seen by (lame) photon telescopes
  - ~40 known, ~6 well studied
- Randomly generate initial populations of stars and evolve them in time
- Track mass transfer, period evolution, gravitational wave emission, tidal effects
- Result: population of stars we use to compute the gravitational wave signal from the entire galaxy

Belczynski, Benacquista, Larson & Ruiter (2006, 2008)
Benacquista, Larson & Taylor (2007)
Larson, Benacquista & Taylor (2008)

The Mass Transfer Population

- Mass transferring binaries are important!



Ruiter, Belczynski, Benacquista & Larson (2006, 2008)

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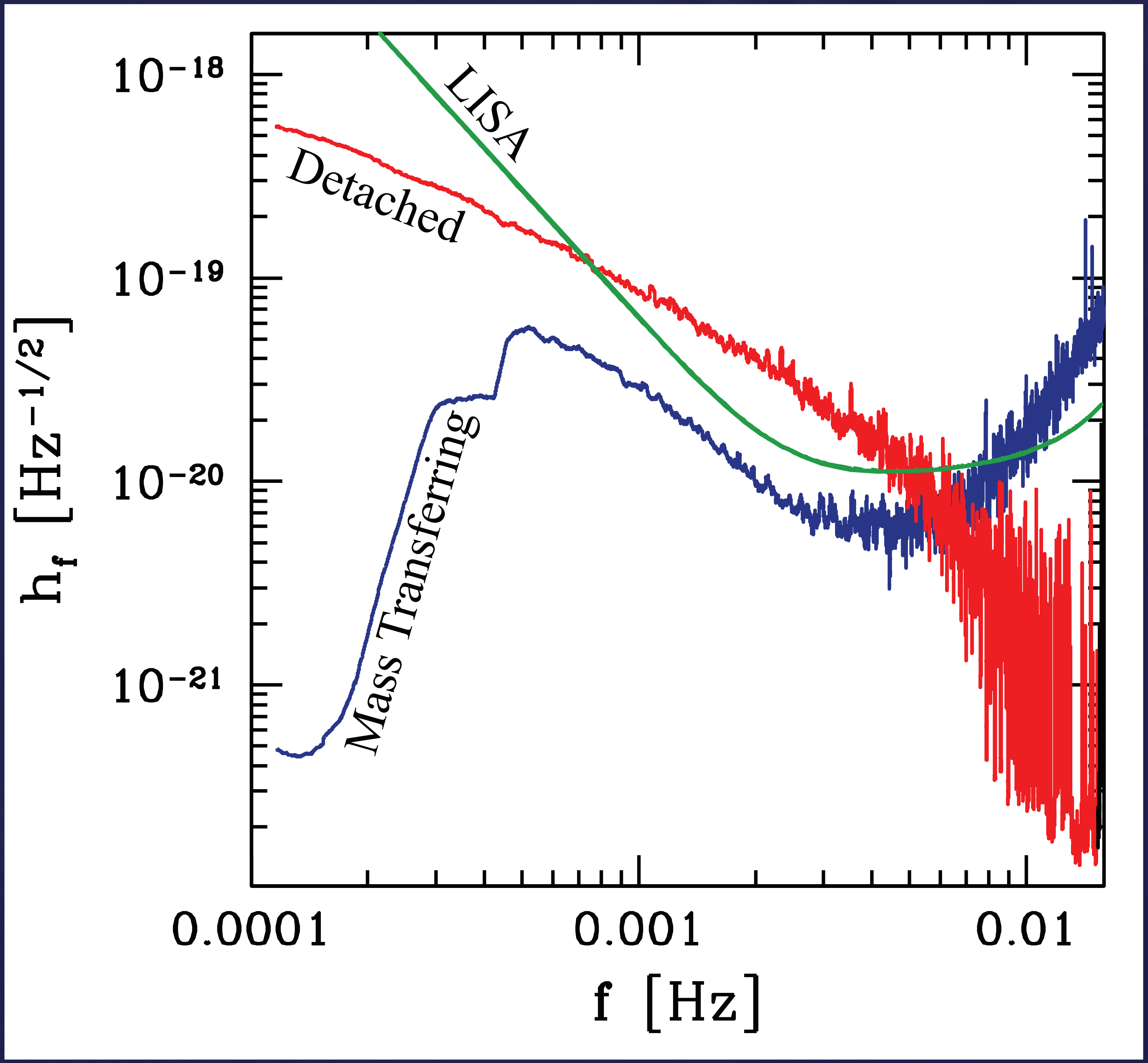

Ruiter, Belczynski, Benacquista & Larson (2006, 2008)

Summary

- Binaries are **signal** not **noise**! They encode:
  - Information about binary evolution
  - Information about the total population of binaries
  - Information about the shape of the galaxy
  - Important science with individual multi-messenger binaries (e.g. "the mass of the graviton")
- It may be the case that the total signal from the galaxy may be quite different than we expect!